CALiPER Round 7 Testing Results and SSL Product Life Issues

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on behalf of the U.S. Department of Energy

April 9, 2009

Presentation Overview

Introductions and Project Background

- Robert Lingard, Pacific Northwest National Laboratory

CALiPER Round 7 Testing Results

- Heidi Steward, Pacific Northwest National Laboratory

SSL Product Life Issues

- Eric Richman, Pacific Northwest National Laboratory

Questions & Answers

- Heidi Steward, Eric Richman and Mia Paget
  Pacific Northwest National Laboratory

CALiPER Round 7 Testing Results

Heidi Steward, LC
Research Engineer
Pacific Northwest National Laboratory

CALiPER Scope

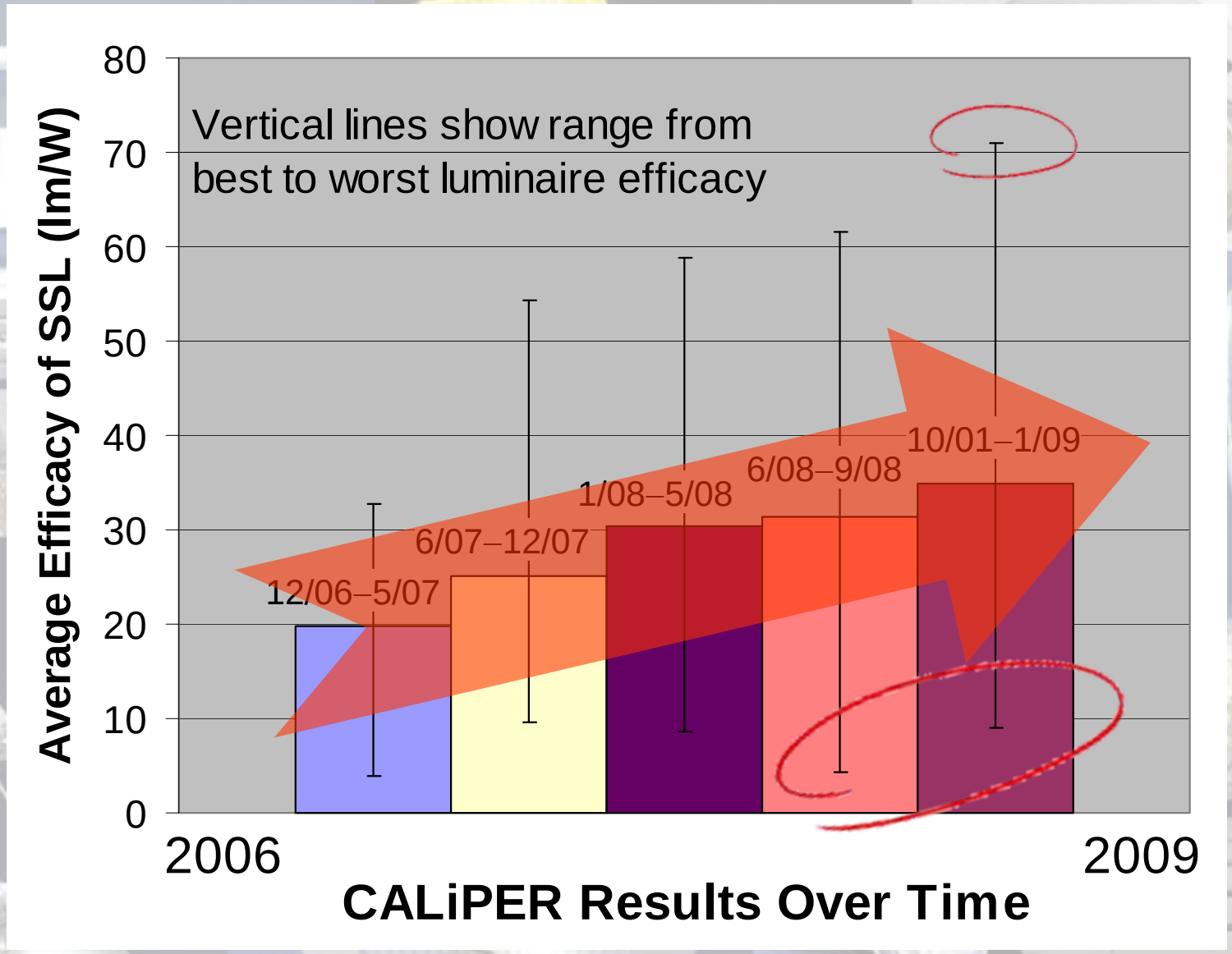
CALiPER SCOPE: General Illumination

SOLID-STATE LIGHTING PRODUCTS

SSL Luminaires and Replacement Lamps

- Lots of marketing hype, but where do we get the truth?
  - Which products are good? Which products aren't?
  - How do they compare to what we know?
  - How do we avoid the early negative CFL experience?

CALiPER Testing: Measurable Progress

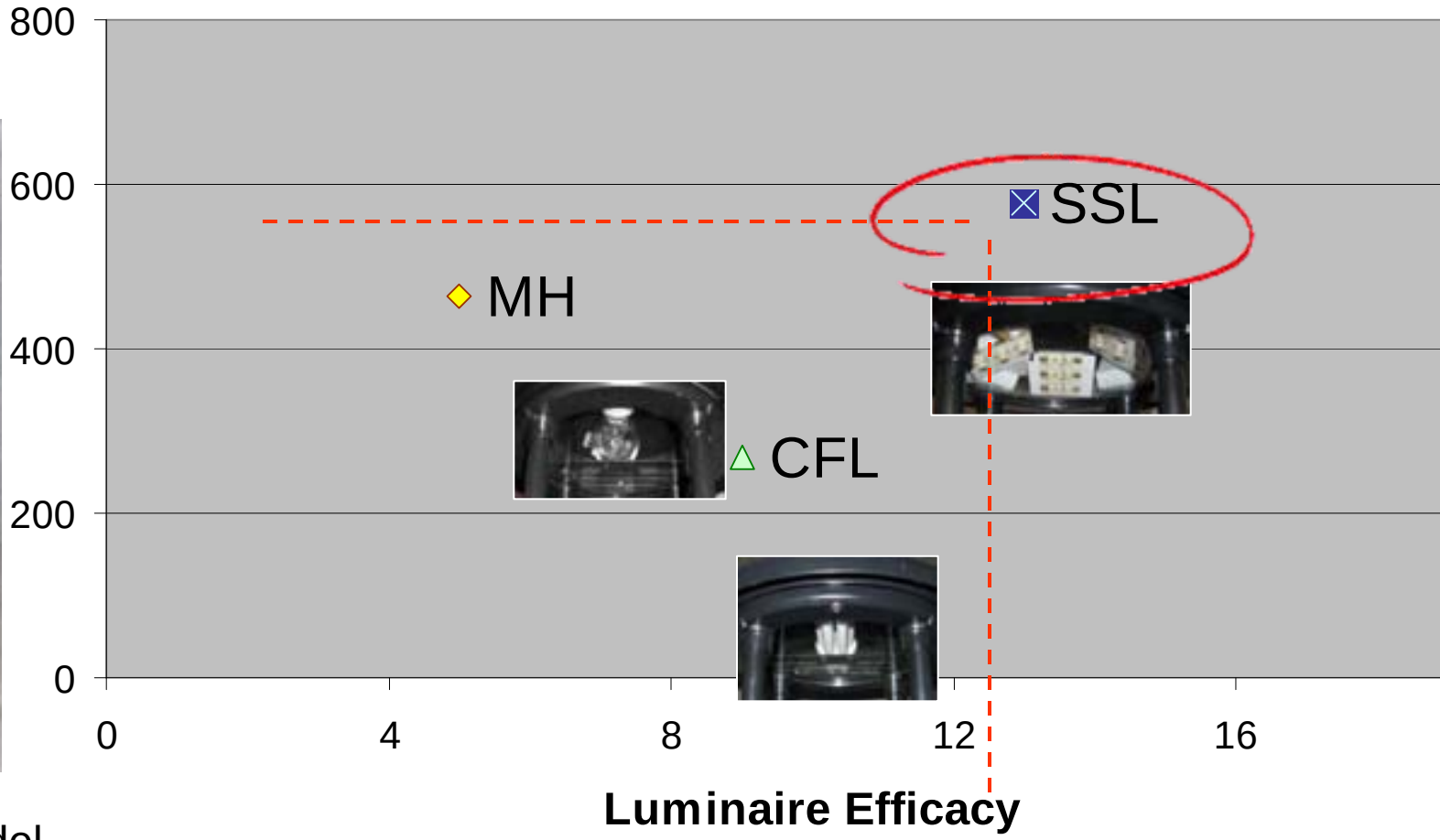


Recent CALiPER Testing: Round 7

- Outdoor Fixtures
  - Streetlights
  - Bollards
- Downlights
- Replacement lamps
  - Directional (MR16, PAR…)
  - Omni-directional (A-lamp)
- Side-by-side comparisons

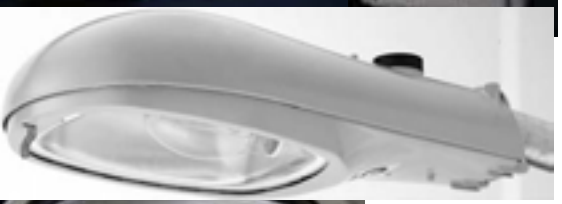
Outdoor Applications

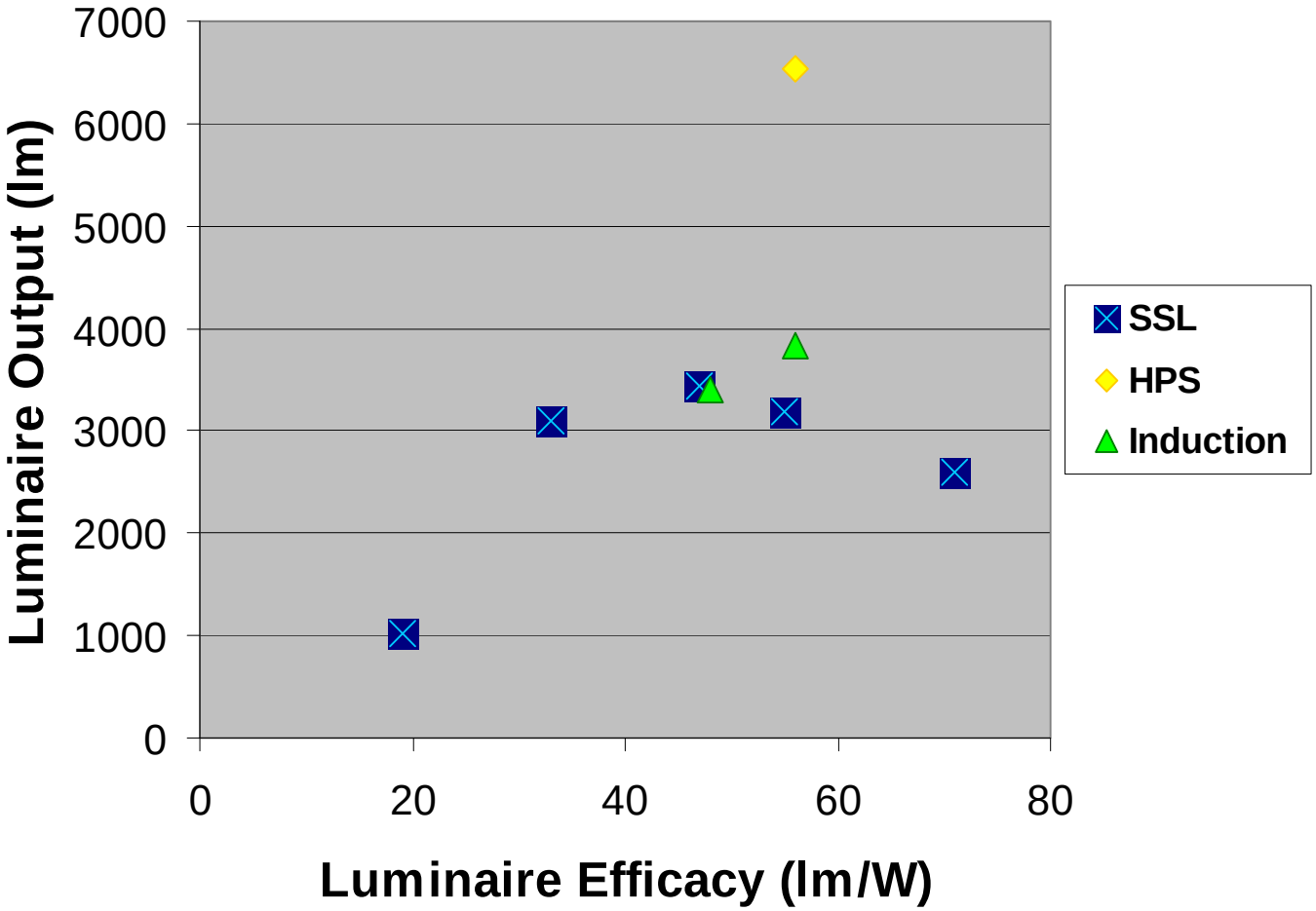
Bollards
Side-by-Side Comparison



- Same Model
- Similar Distribution
- With House-Side Shield

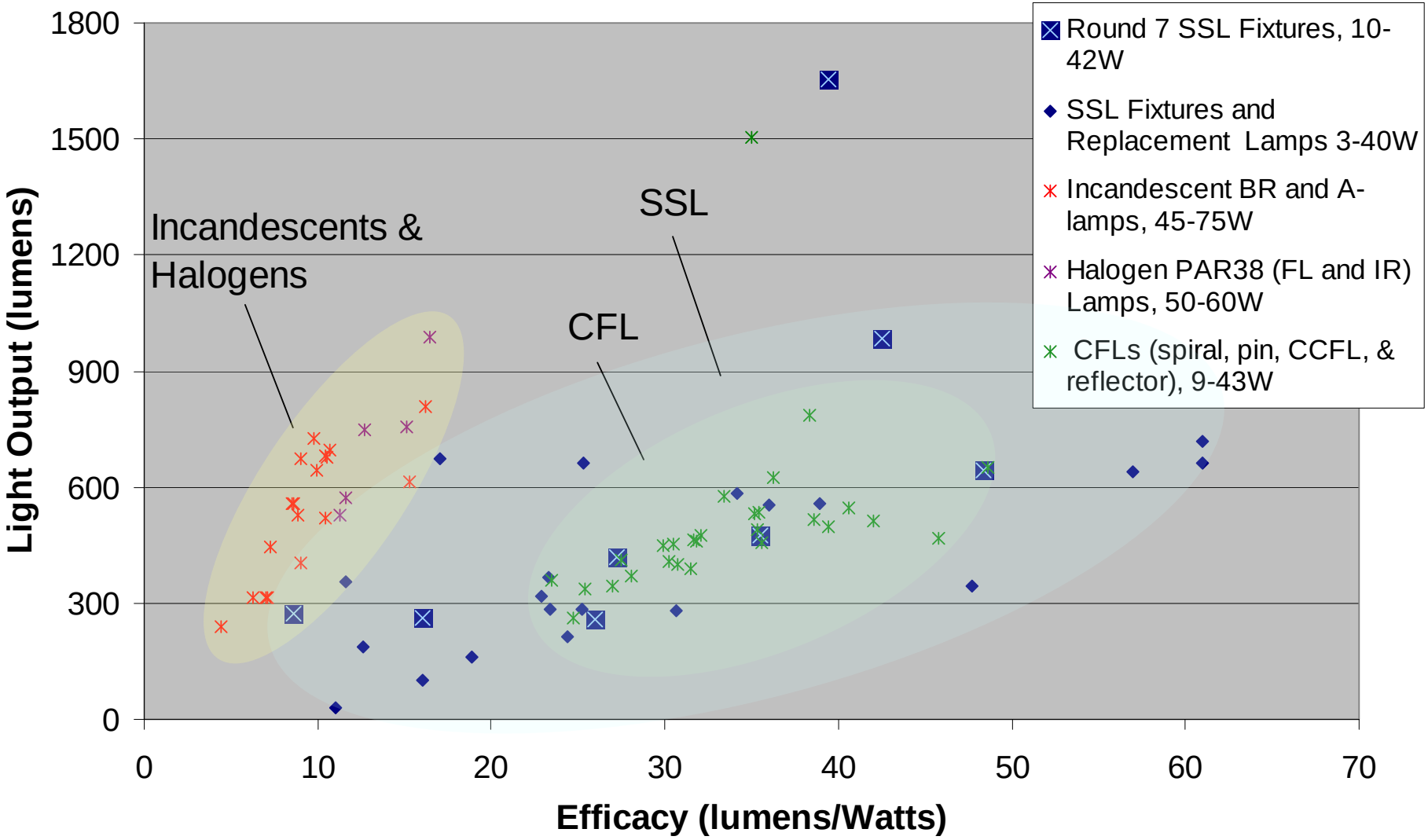
Streetlight Comparison





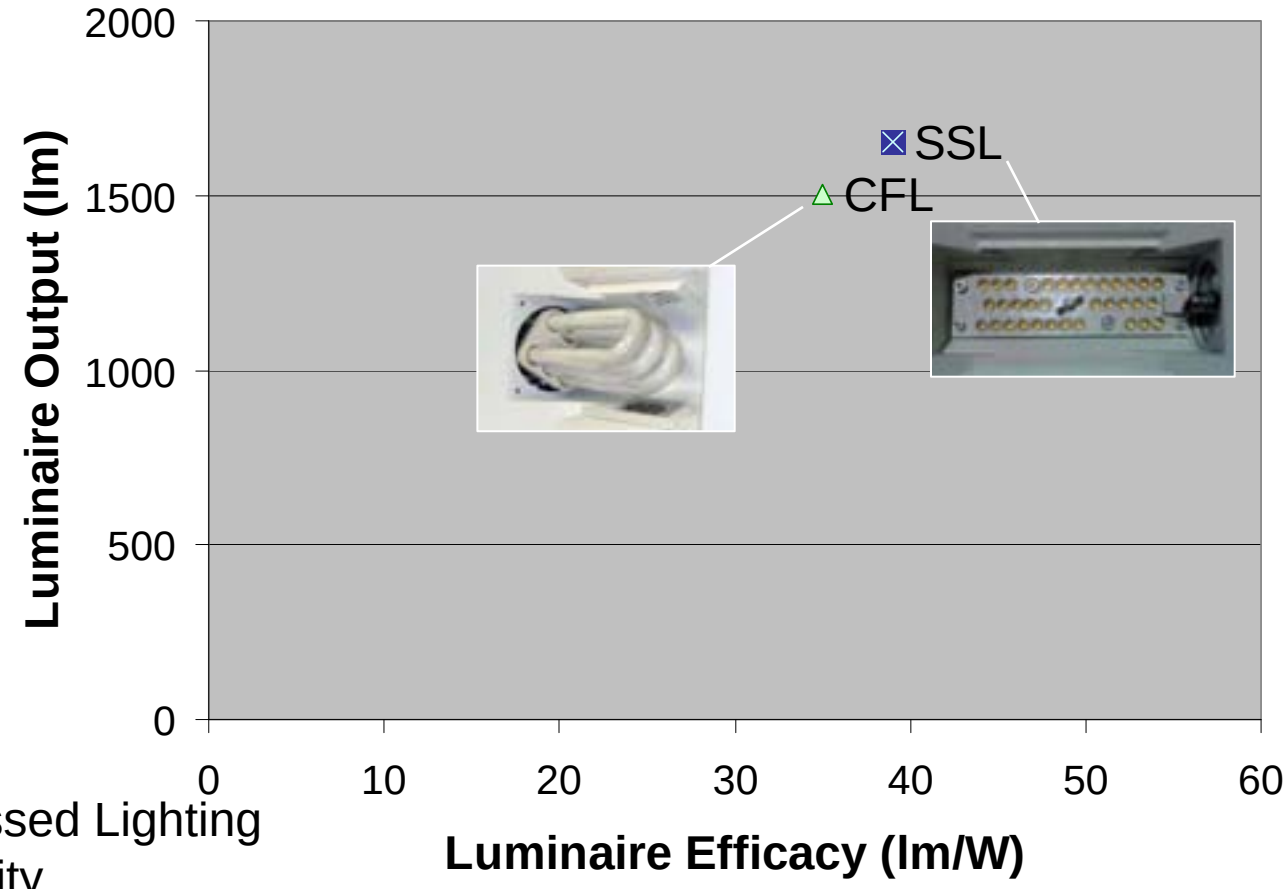
Downlights

SSL Downlight Performance



Results compiled from CALiPER and other DOE testing, NLPIP reports, and manufacturer catalogs. A-lamps, R-lamps, and PAR lamps are tested in situ, or a fixture loss factor is applied to bare lamp performance based on CALiPER in situ versus bare lamp testing.

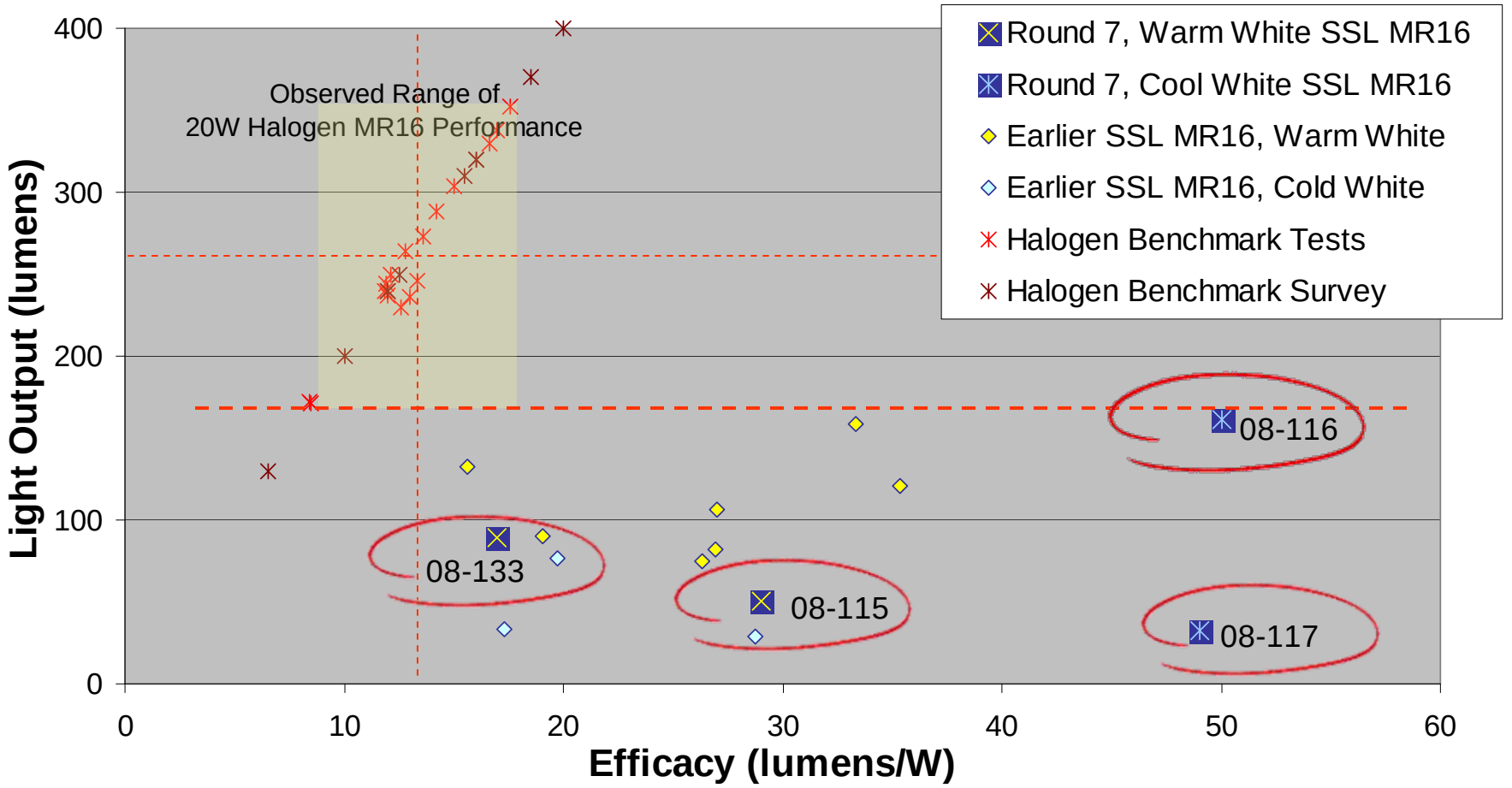
Downlights
Side-by-Side Comparison



- Same Model
- 1’ x 1’ Square
- Volumetric Recessed Lighting
- Same Color Quality
- Similar Distribution
- SSL Initial Cost ≈ 2 x CFL Initial Cost

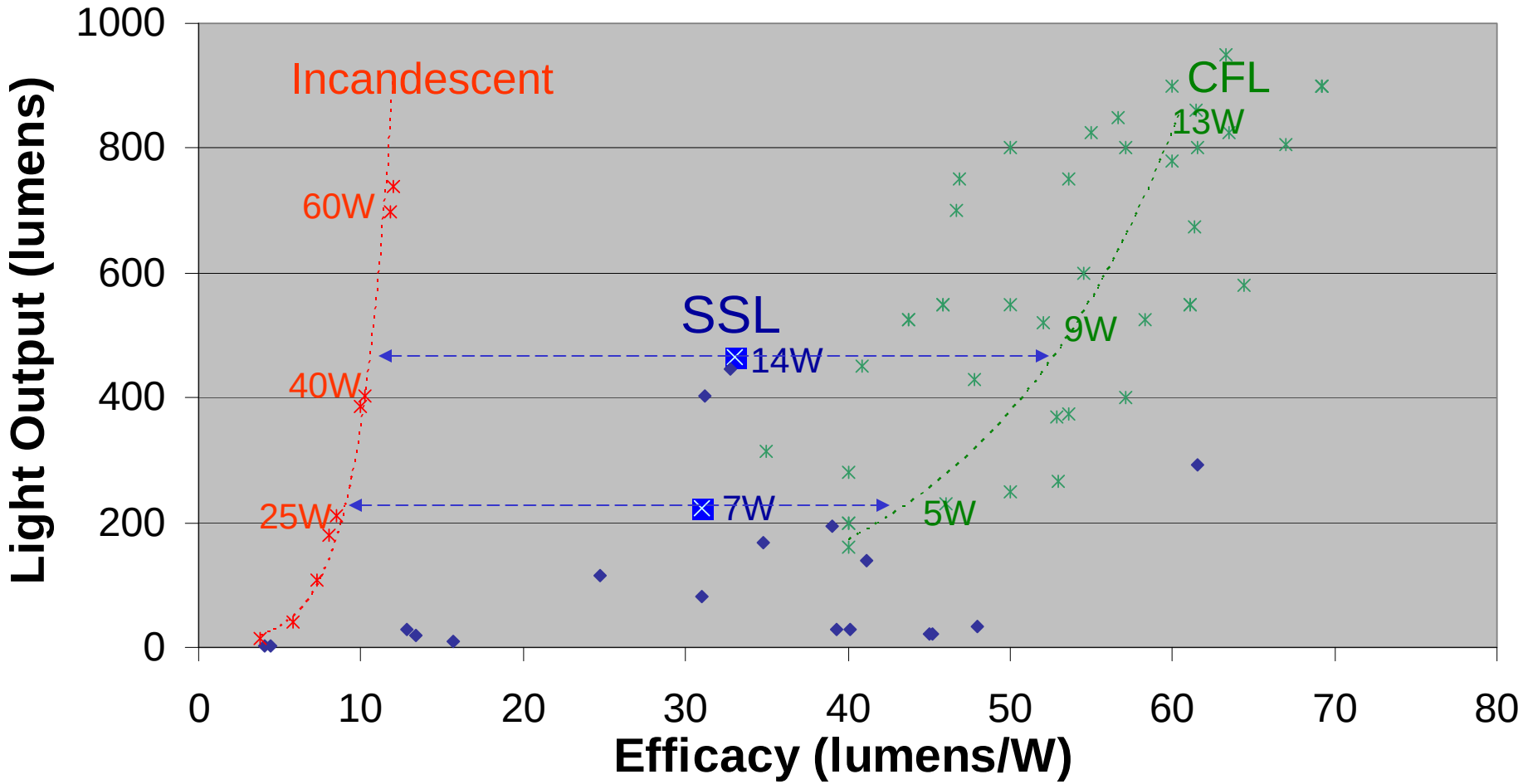
Replacement Lamps

SSL MR16 Products Approaching 20W Halogen Output Levels



Benchmark values are based on CALiPER benchmark tests, surveyed ratings, and averaged manufacturer ratings for 20W MR16 halogen lamps. Values are based on initial output, not average life-time output. 08-117 was tested at 120V input, all others with 12V input.

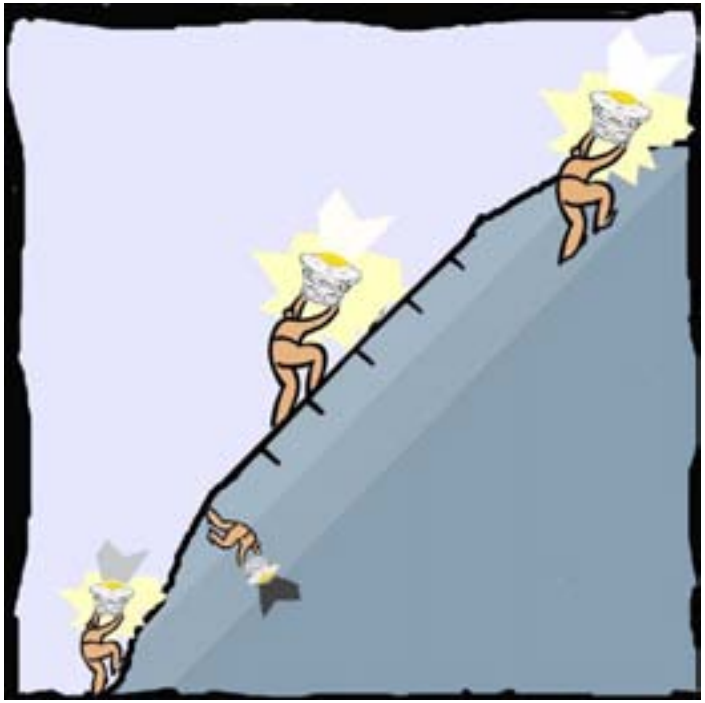
Omnidirectional Replacement Lamps



Benchmark values are based on CALiPER benchmark tests, surveyed ratings, and averaged manufacturer ratings for incandescent and CFL lamps. Values are based on initial output, not average life-time output.

Be Wary of Potential Pitfalls

- **Color**: some 'white' light products are quite 'bluish' or quite greenish
  - Both CCT and D_{uv} matter
- **Comparisons**: absolute ≠ relative photometry
  - Compare performance at the luminaire level
- **Claims**: product literature is often erroneous or misleading
- **Lifetime performance**: true, *in situ*, long-term performance is still a great unknown
  - Initial lumen maintenance results are mixed
- **Learning curves**: some manufacturers are at the top, many still just setting foot on the slope



Ascending the SSL Learning Curve

Looking for the Full Story?

www.ssl.energy.gov/caliper.html

- Round by round summaries
- Detailed photometric reports
- Benchmark reports
  - Linear replacement lamps
  - MR16 replacement lamps
  - Omni-directional replacement lamps
- Exploratory reports
  - Dimming study
  - Long-term testing study
  - Variability and repeatability study

CALiPER

Thank You!

DOE CALiPER reports:
www.ssl.energy.gov/caliper.html

CALiPER Contacts:
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SSL Product Life Issues

Eric Richman, LC
Senior Research Engineer
Pacific Northwest National Laboratory

SSL (LED) “Life”

What is it?

How is it measured?

Seoul Semiconductor

Cree XLamp

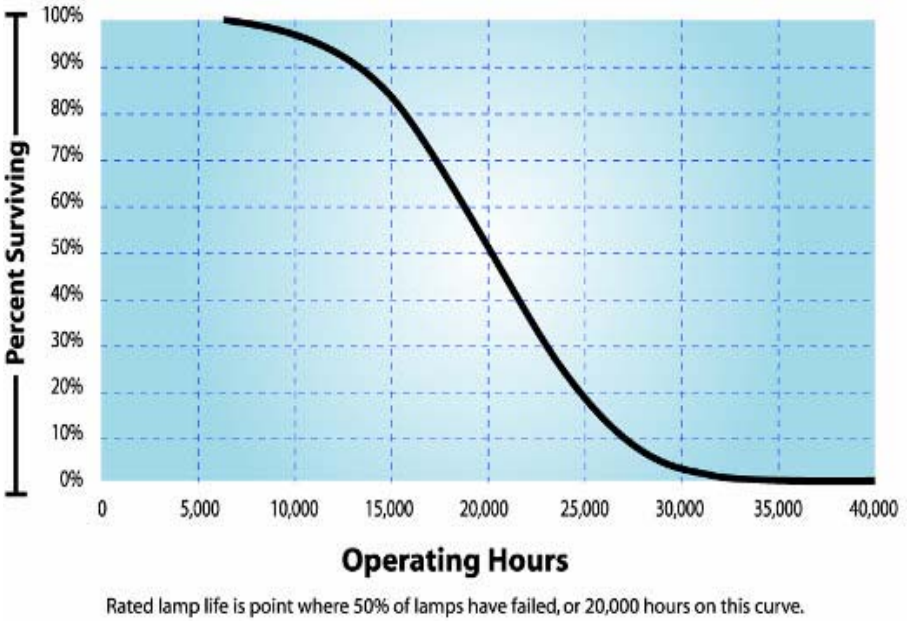
Lamina Titan

LED “Life” - Important but Elusive

- Light source “Life” is **critical** for -
  - Lighting design - technology choice and application
  - Energy and cost-effectiveness analysis
  - Big issue in LED technology characteristic (hype)
  - Often heavily weighted for LED cost-effectiveness
- LED “Life” is not simple or obvious
  - LEDs operate differently than other sources
  - LEDs do not have a clear “End of Life”

What is “Life” for Lighting?

- “Operational failure”
  - Most light sources “burn out” (End of “Life”)
  - Lamp life is typically rated at 50% failure rate
  - ***LEDs*** *typically don’t fail (no filament to “burn”)*

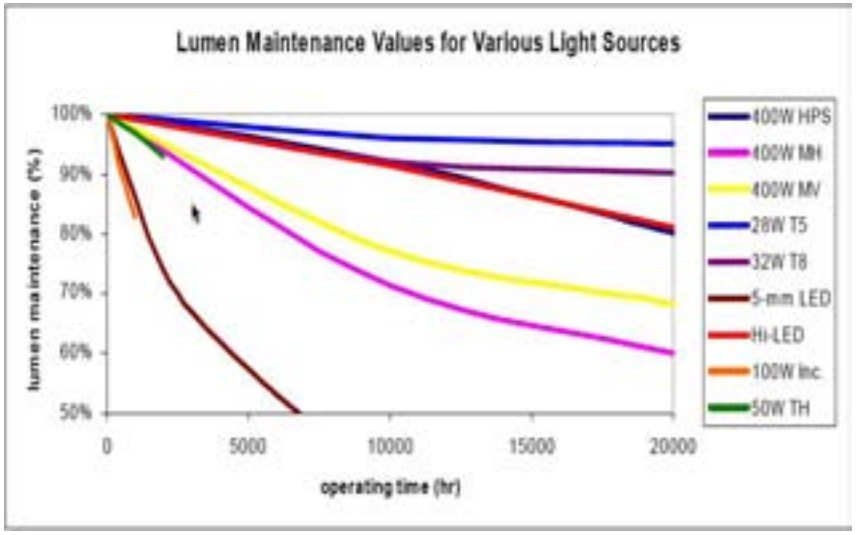


Rated lamp life is point where 50% of lamps have failed, or 20,000 hours on this curve.

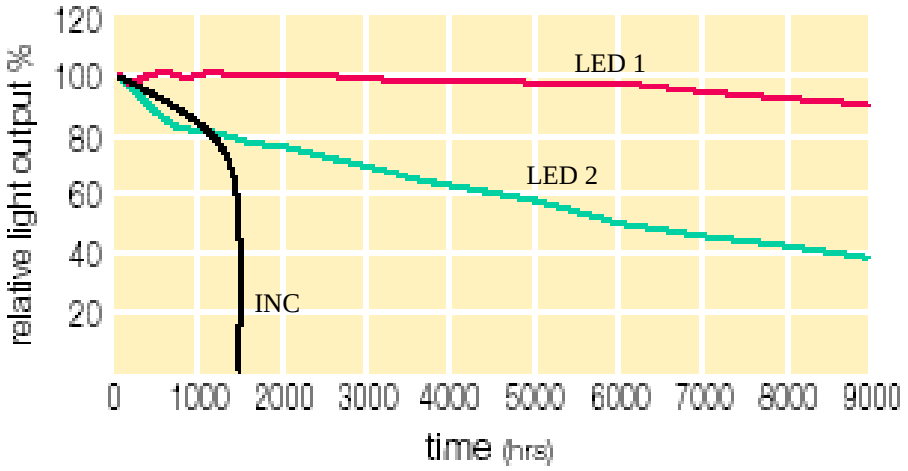
- Breakage
  - Most lamps (glass) can break (End of “Life”)
  - ***LEDs*** *are inherently small and sturdy*

"Life" for LEDs

- Useful light output (Lumen Maintenance)
  - All light sources degrade but most just "burn out" before serious loss of light output
  - LEDs continue to degrade – eventually beyond useful light output



Source: Lighting Research Center - Rea 2000; Bullough 2003



Source: Spectrum Illumination

"Life" Metrics for LEDs

- L_{70}, L_{50}
  - Initiated by LRC as relative % of initial output
  - L70 for applications where illuminance level is important, L50 for non-critical needs
- B_{50}, B_{10}
  - Initiated by Lumileds to relate statistical "failure" of a sample that includes low output (i.e. below L_{70}) and component failure.

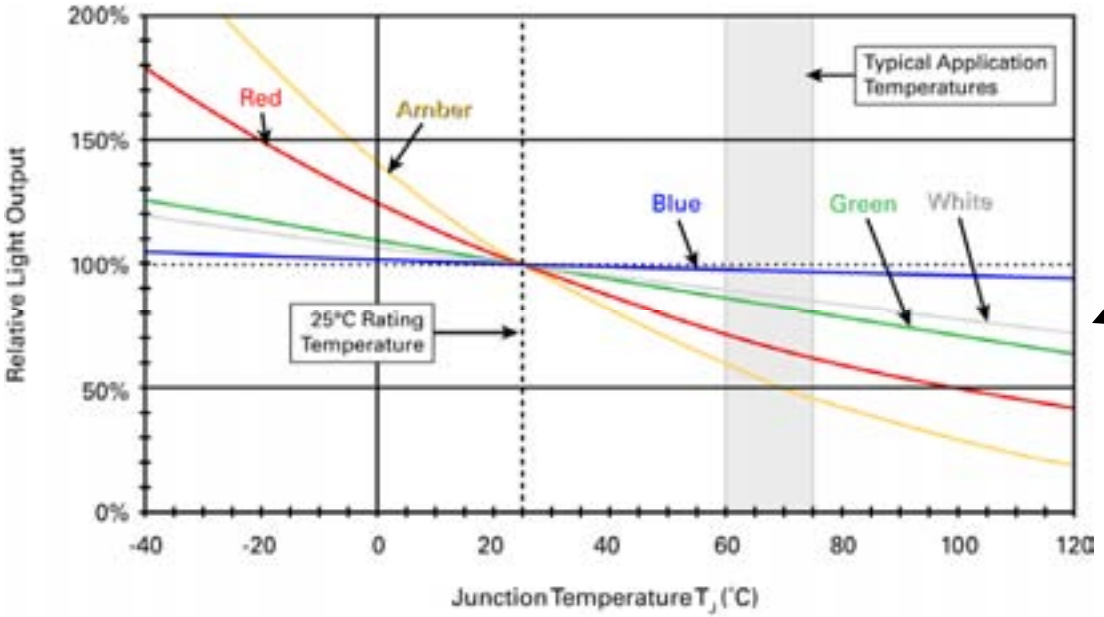
L_{70}, B_{50} = the time ("life") when the light output of 50% of the LEDs in a sample will degrade to 70% of initial light output

What effects LED “Life”?

- Environment
  - Heat, cold, humidity
- Material Stability
  - connections, encapsulate, phosphors
- Mechanical and Electrical conditions
  - vibration, voltage, current
- Installation Architecture
  - Heat sinking!

Environment and LED "Life"

- **Heat….is the primary factor in LED light output**

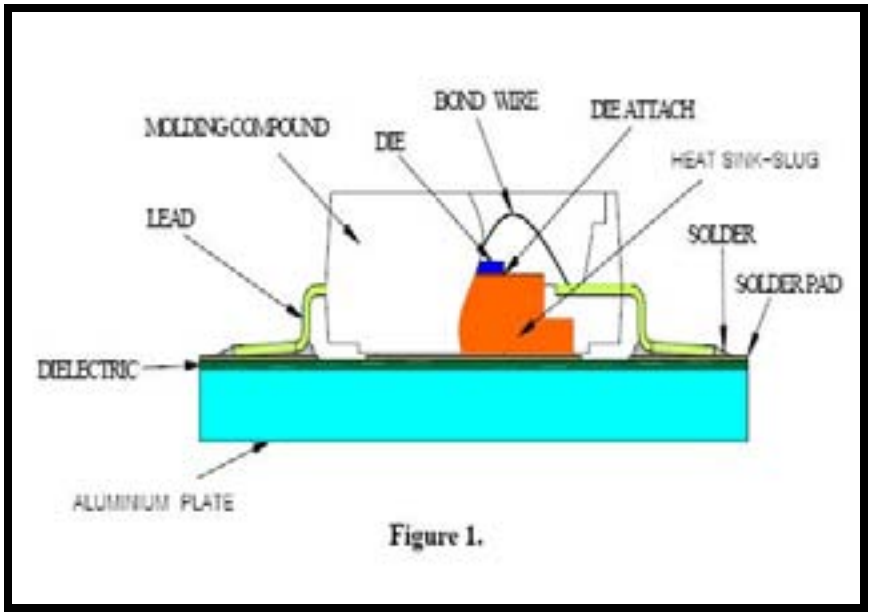


Higher operating temperature = lower light output

- Cold….LED technology appreciates natural cooling
- Humidity….may effect connections and associated housing materials

Material Stability

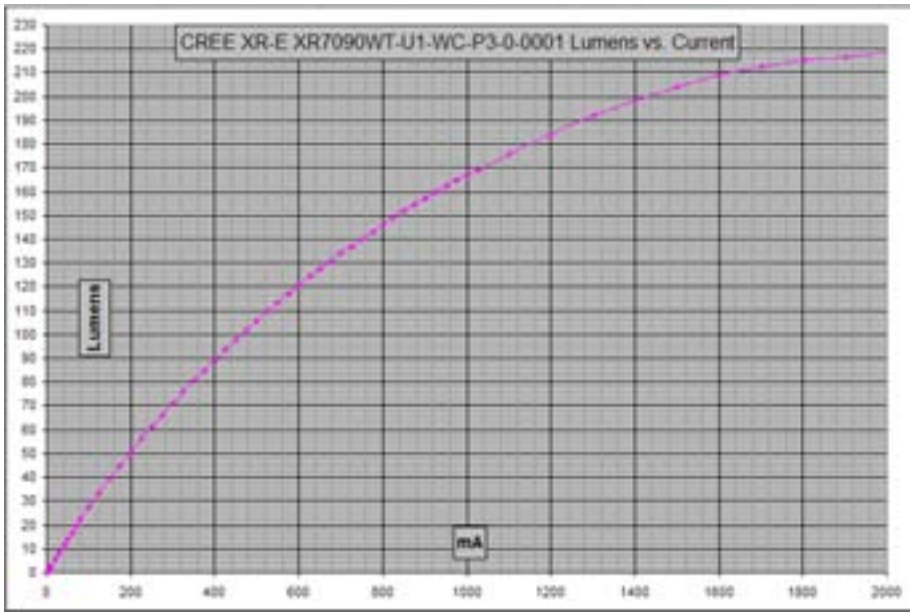
- Connections….solder joints and leads can be the weakest point of an LED module (and luminaire)
- Encapsulate (and lens)….can degrade and effect light output or failure
- Phosphors….can wear out over time or become compromised



Seoul Semiconductor, Ltd

Mechanical and Electrical Conditions

- Vibration….mostly effects the luminaire housing and auxiliary components
- Voltage/Current….variation can overdrive or underdrive the LED effecting output



Source: www.molalla.net/%7Eleeper/creexre.png

Installation Architecture

Heat sinking!

- LED performance is driven by heat:
  - LED modules must have effective heat sinking
  - Luminaire housing and components can affect heat transfer
  - **Tested performance of LED modules will not remain true when heat sink is compromised!**

Measurement of LED "Life"

...that is… measurement of lumen maintenance

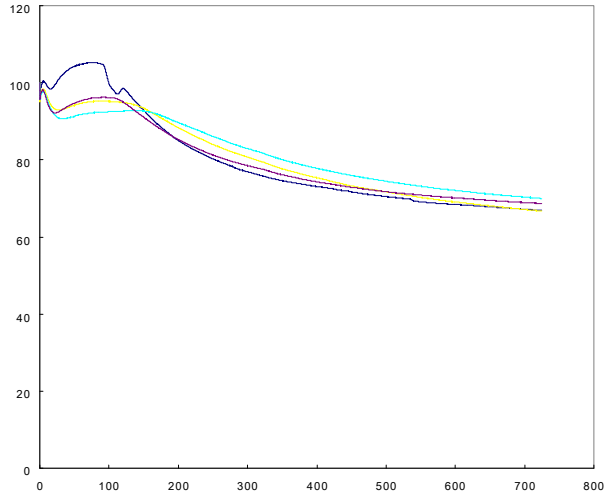
IES LM-80

- Provides measurement format and repeatability conditions.
- Covers LED packages, arrays and modules only – not complete luminaires

LM-80 does not define or provide methods for estimation of life from testing data

"Life" Estimation Issues

- Estimate of life requires lengthy testing
  - 6000 hours (~ 8 months) specified by LM-80
  - may not be enough for best estimate
- Data at multiple temps needed for use in luminaire evaluations
- Seasoning ("burn-in")
  - Characteristic early "bump" in degradation can significantly effect extrapolation

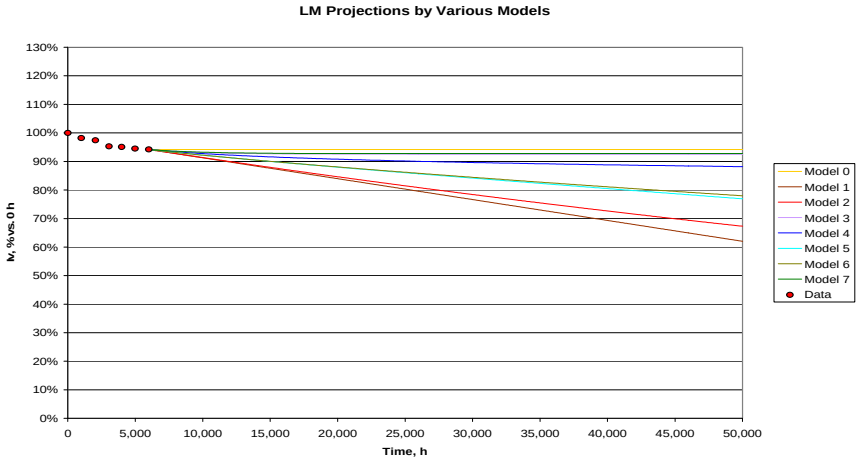


IES TM-21 (Life Estimation)

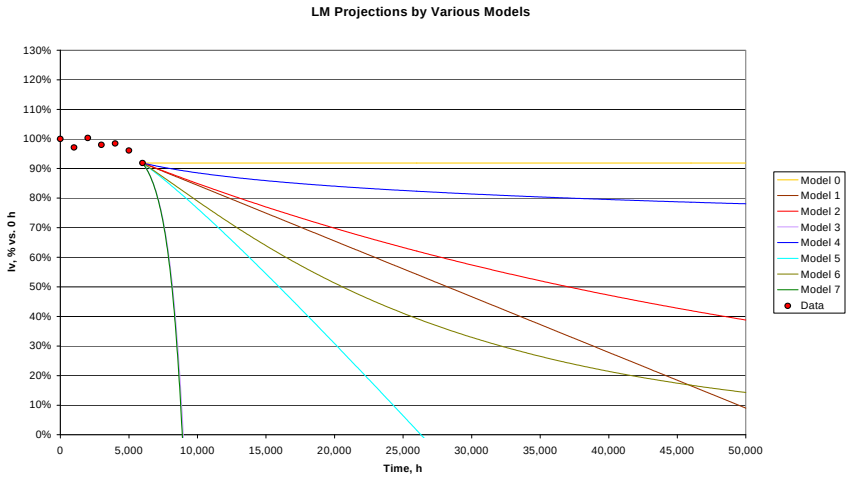
- Test Method intended to provide a prediction of LED Lumen maintenance ~ lifetime
- Based on LM-80 testing (6000 hours) but some data showing changes near 6000 hr
- Leaning toward conservative approach
- Currently exploring multiple models representing potential degradation paths

Life Estimation Method

- Light output is commonly exponential over time – generally good fit



- ….but early “Bumps” in degradation can skew results



Bottom Line…..

- LED “Life” is primarily tied to anticipated level of light output
- More testing needed to comfortably understand LED lumen maintenance
- Be mindful of the lack of LED operational failure as End of Life
- Consider a conservative approach when assigning value to life

Thank you!

For more information

DOE CALiPER, including summary and detailed testing reports, benchmark reports, and exploratory studies:
www.ssl.energy.gov/caliper.html

DOE SSL Standards Development, including current standards and test methods, and updates on standards under development:
www.ssl.energy.gov/standards.html

DOE's Solid State Lighting Program:
www.SSL.energy.gov